

A More Accurate and Efficient Technique Developed for Using Computational Methods to Obtain Helical Traveling-Wave Tube Interaction Impedance

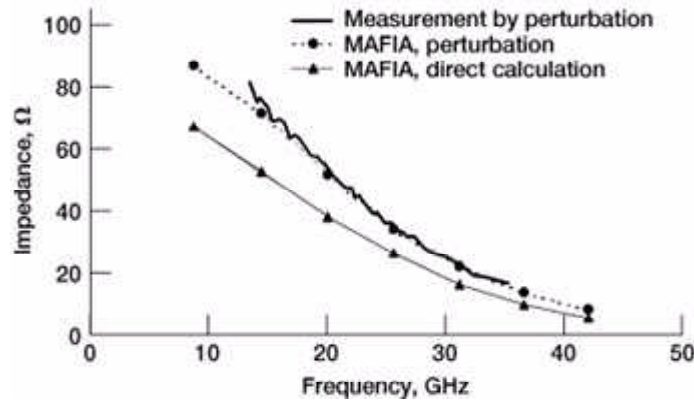
The phenomenal growth of commercial communications has created a great demand for traveling-wave tube (TWT) amplifiers. Although the helix slow-wave circuit remains the mainstay of the TWT industry because of its exceptionally wide bandwidth, until recently it has been impossible to accurately analyze a helical TWT using its exact dimensions because of the complexity of its geometrical structure. For the first time, an accurate three-dimensional helical model was developed that allows accurate prediction of TWT cold-test characteristics including operating frequency, interaction impedance, and attenuation. This computational model, which was developed at the NASA Lewis Research Center, allows TWT designers to obtain a more accurate value of interaction impedance than is possible using experimental methods.

Obtaining helical slow-wave circuit interaction impedance is an important part of the design process for a TWT because it is related to the gain and efficiency of the tube. This impedance cannot be measured directly; thus, conventional methods involve perturbing a helical circuit with a cylindrical dielectric rod placed on the central axis of the circuit and obtaining the difference in resonant frequency between the perturbed and unperturbed circuits. A mathematical relationship has been derived between this frequency difference and the interaction impedance (ref. 1). However, because of the complex configuration of the helical circuit, deriving this relationship involves several approximations. In addition, this experimental procedure is time-consuming and expensive, but until recently it was widely accepted as the most accurate means of determining interaction impedance.

The advent of an accurate three-dimensional helical circuit model (ref. 2) made it possible for Lewis researchers to fully investigate standard approximations made in deriving the relationship between measured perturbation data and interaction impedance. The most prominent approximations made in the analysis were addressed and fully investigated for their accuracy by using the three-dimensional electromagnetic simulation code MAFIA (Solution of Maxwell's Equations by the Finite Integration Algorithm) (refs. 3 and 4). We found that several approximations introduced significant error (ref. 5).

To further validate the three-dimensional computational helical model, researchers duplicated the experimental perturbation method by simulating the helical circuit with a cylindrical dielectric rod of size and material properties consistent with the experimental setup. The difference in frequency between the perturbed and unperturbed circuits was obtained. Then, the interaction impedance was calculated using the previously mentioned approximate formulation relating frequency difference to interaction impedance. The following graph, which compares the results with measured values, emphasizes the

accuracy of the code. The interaction impedance was calculated with the exact formula used in MAFIA and is also plotted in this graph. The results calculated directly with MAFIA are consistently lower than measured results, with an average difference of 26.6 percent.



On-axis interaction impedance obtained by measurement and by using MAFIA with the perturbation method and direct calculation.

The demonstrated inaccuracy of approximations in the derived experimental impedance formula, along with the large discrepancy between these measured impedance data and direct calculations using MAFIA, verifies that a more accurate value of interaction impedance can be obtained by using three-dimensional computational methods. In addition, this implies that MAFIA will yield large savings in time and cost in comparison to expensive and time-consuming experimental cold-test measurements.

References

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